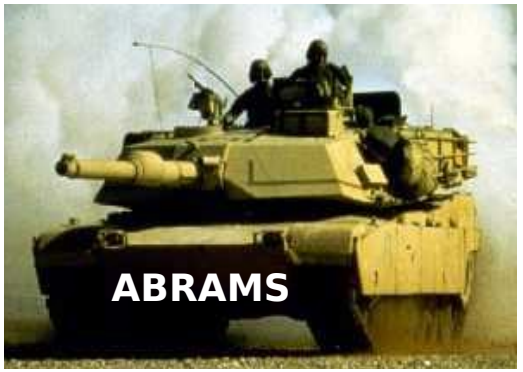
Erosion Mitigation Technology for Large Caliber Launch Systems



presented by
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part of the US Army Armaments Research, Development and Engineering Center

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LARGE CALIBER GUN EROSION

Direct Fire

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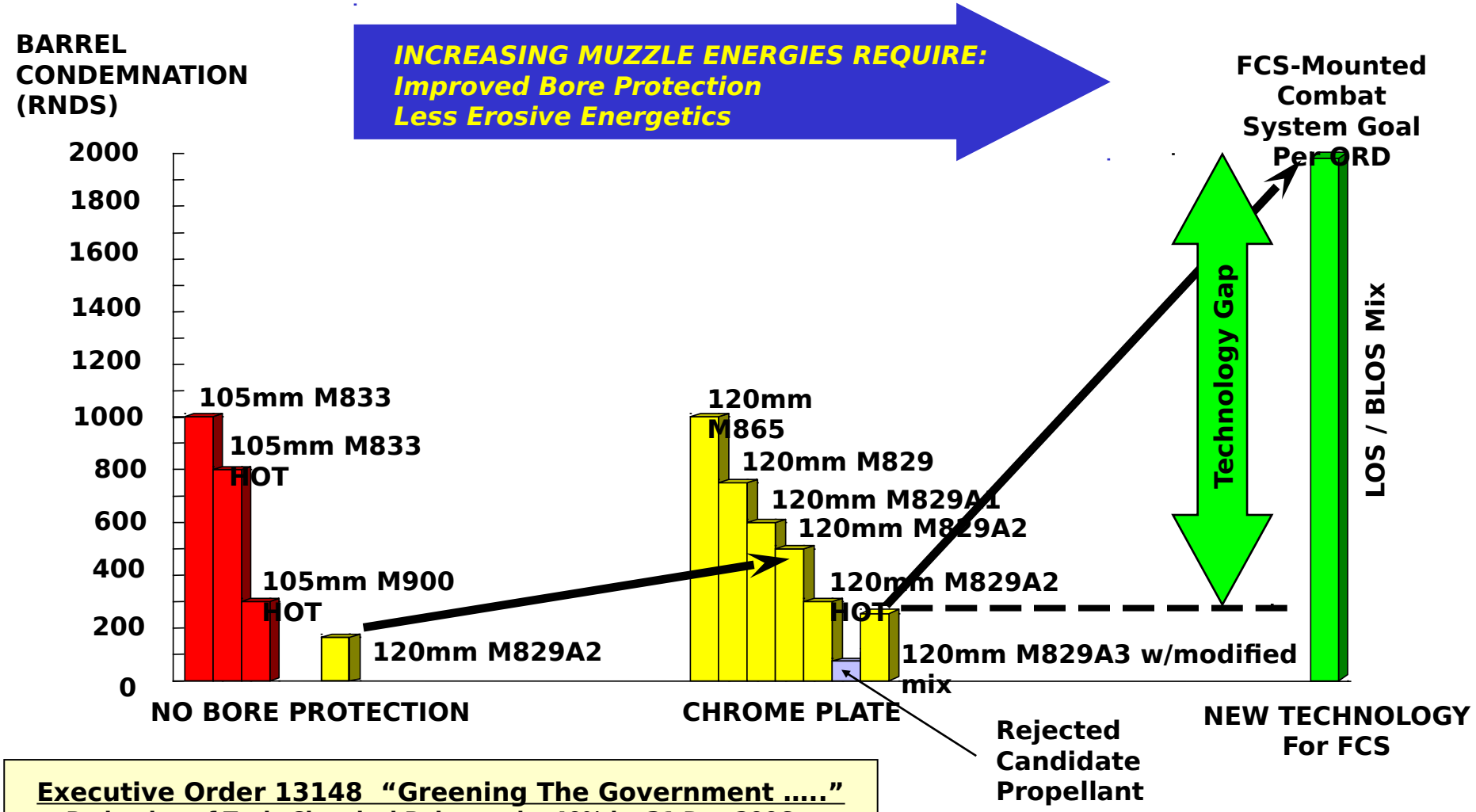

Executive Order 13148 "Greening The Government ....."

Reduction of Toxic Chemical Releases by 40% by 31 Dec 2006

Reduction of Toxic Chemical Usage by 50% by 31 Dec 2006

120mm GUN BARREL DEGRADATION

Classic Erosion Defined

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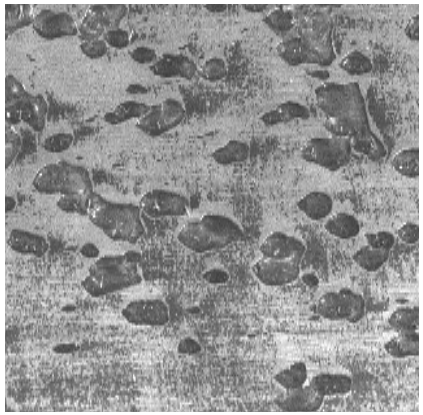
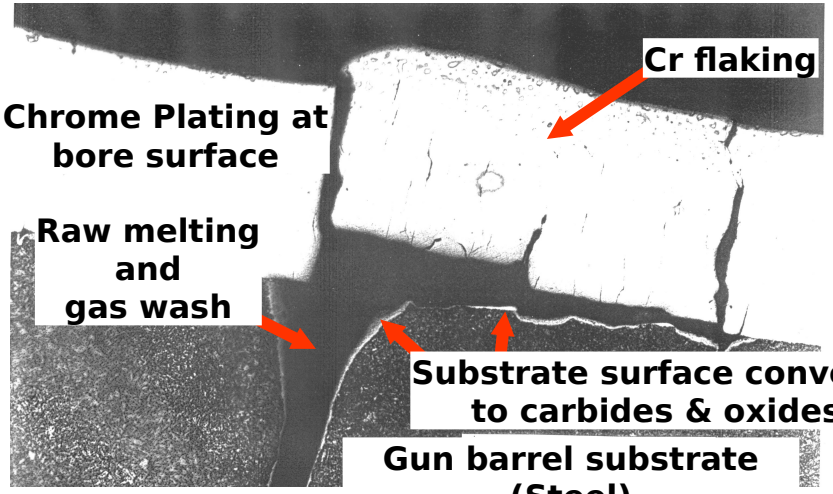
101 rounds M829
771 rounds Total



39 M829E3 Rejected candidate
214 Total rounds

ABRAMS 120mm GUN


Cr flaking
Chrome Plating at bore surface
Raw melting and gas wash
Substrate surface converts to carbides & oxides
Gun barrel substrate (Steel)

- HC Chrome is produced in an “as cracked” condition offering path to substrate
- HC Cr contaminants off-gas causing further material volume shrinkage and stress-relief cracking
- Combustion products:
  - Penetrate cracks
  - Alter steel substrate phase
  - Convert substrate surface to carbides & oxides
  - Lowers MP of substrate surface
- Gas wash:
  - Removes lower MP substrate surface
  - Erodes Cr foundation (compromised adherence)

Departing Cr exposes more substrate to gh velocity gas wash and further erosion

LARGE CALIBER GUN COATING REQUIREMENTS

Material & Deposition Process Requirements

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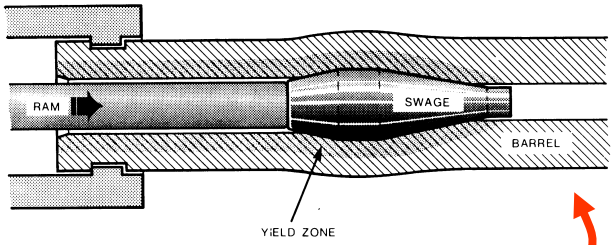
MATERIAL CHARACTERISTIC	CRITERIA
Melting Point	*Cr (1875 C) or better*
Elastic Modulus	*Compatible with substrate* ***(facilitates low surface crack densities)***
YS at Elevated Temps	*High*
Fracture Toughness	*High*
Hot Hardness	*High (appropriate)*
Chemical Resistance	*High*
Coefficient of Thermal Exp.	*Compatible with substr*
Thermal Conductivity	*Low*
Reaction w/ Rotating Band	*Inert*
Phase Transformations	*None*



PROCESS CHARACTERISTIC	CRITERIA
Deposition Temperature	*Less than 357C* ***(post autofrettage thermal soak limit)***
Deposit Rate	*1 mil of coating material per hour*
Surface Finish	*Equal or better than 32 RMS at deposition*
Deposition Length	*58 Calibers or greater*
Hazardous Impacts	*None or limited*

EROSION RESISTANT COATING MATERIAL SELECTION

for Large Caliber Guns

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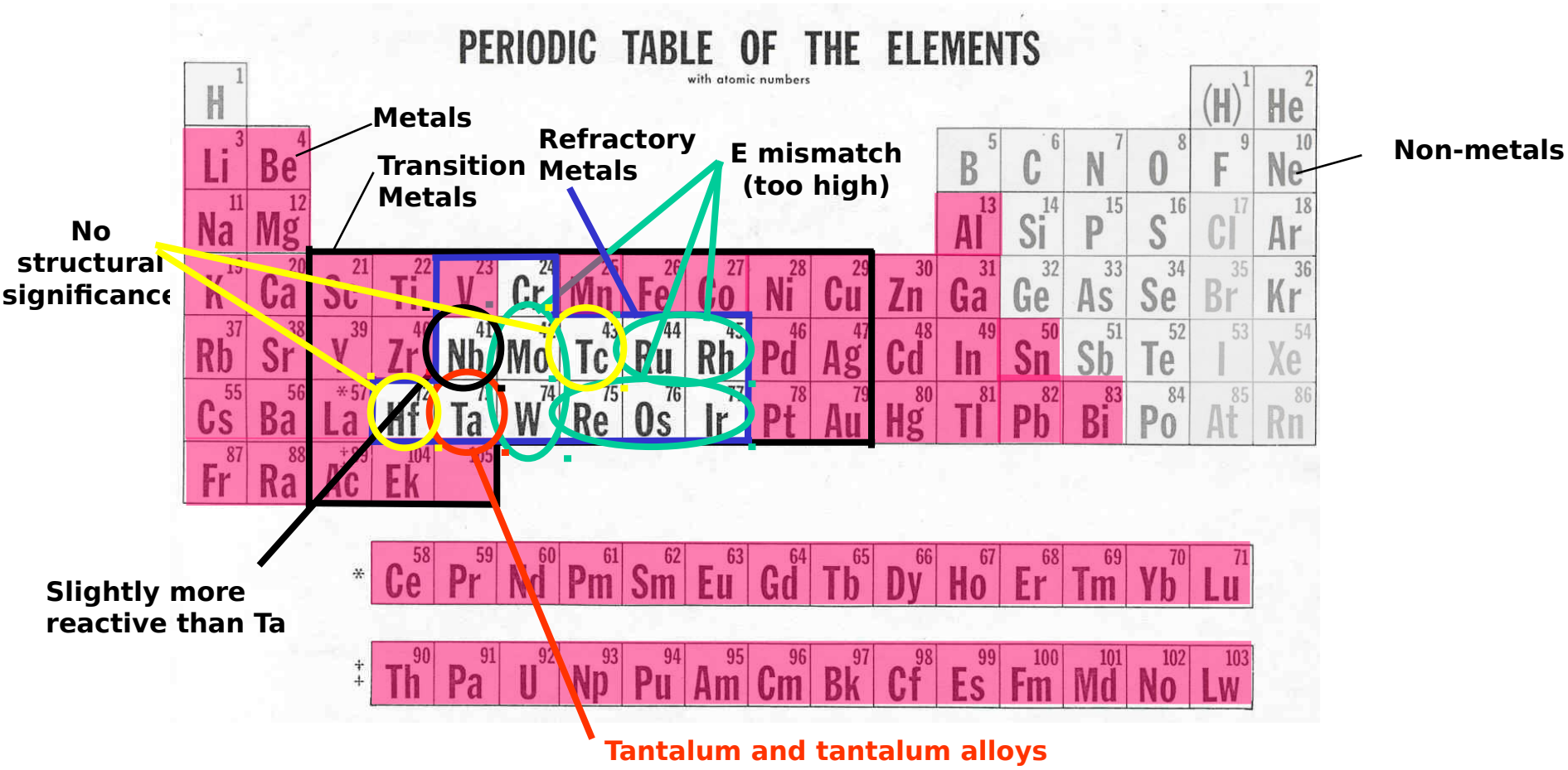

Rh, Ru, Tc, Hf, Nb, Mo, Ta, W, Re, Os, & Ir exceed MP of

COATING DEPOSITION PROCESS SELECTION

for Large Caliber Guns

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FUNCTIONAL REQUIREMENTS	PROCESS									
	Molten Salt	Plasma Spray	Chem. Vapor Dep.	Ion Implant.	Ion Plate	Explosive Bonding		Metal liding	Aqueous Electro-Dep	Cyl Magnetron Sputtering
Autofrettage Stresses Protected				✓	✓			✓	✓	
No Post-process Surface Finish Req	✓			✓		✓	✓	✓	✓	
Acceptable Deposition Rate	✓	✓	✓			✓		✓	✓	
Proper Process Aspect Ratio			✓					✓	✓	
Accept Dim. and Densities over 50 cal								✓	✓	
Acceptable Adhesion	✓					✓		✓	✓	
Dry Process		✓	✓	✓	✓	✓	✓		✓	
Eliminate Hazardous Materials				✓	✓	✓			✓	
Eliminate Air / Water Contamination				✓	✓	✓			✓	

120mm GUN BARREL MANUFACTURING PROCESS

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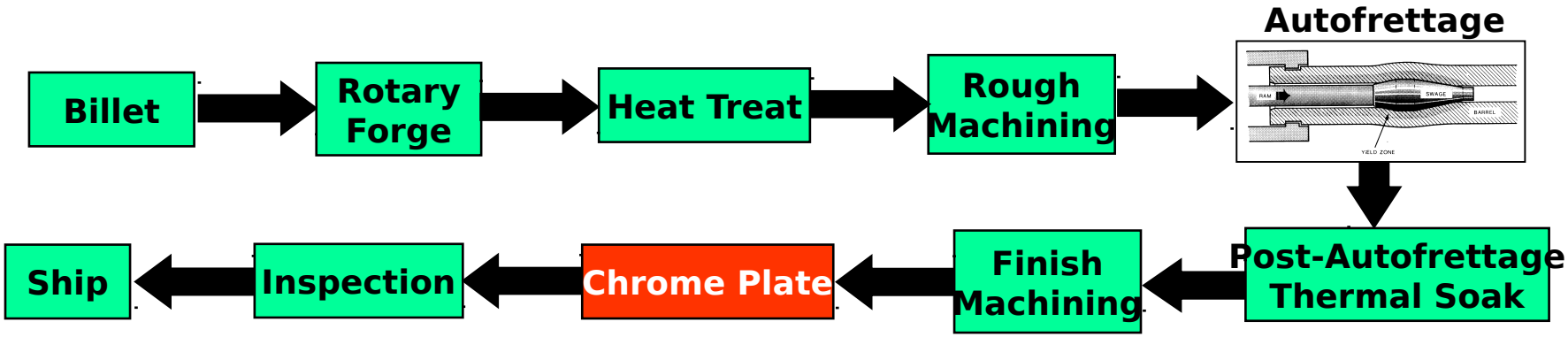

Rotary Forging

Machining

Chrome Plating

Fielding

TECHNICAL APPROACH

Cylindrical Magnetron Sputtering

U.S. Army Benet Laboratories

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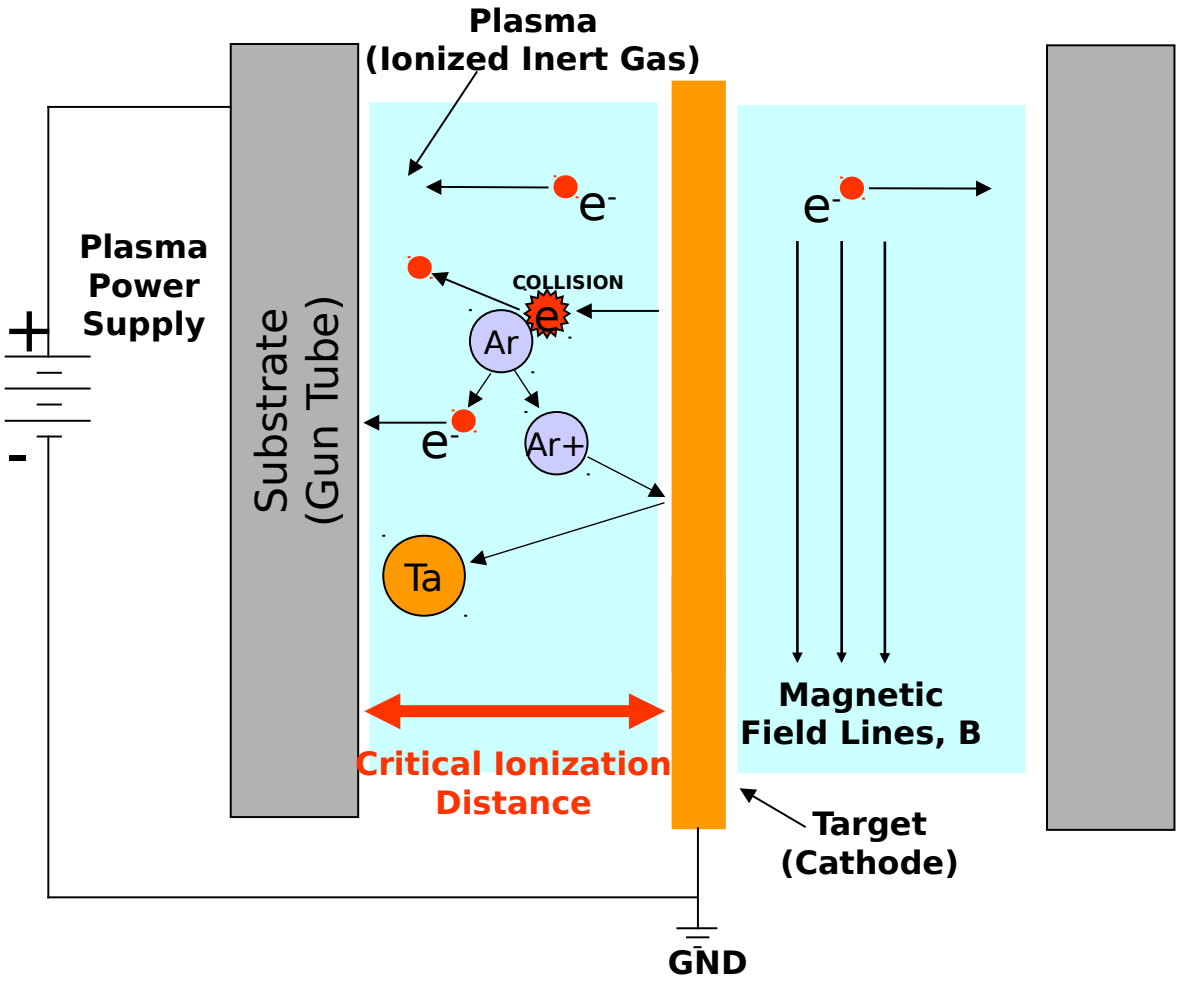

ADVANTAGES

- Environmentally benign
- Can deposit high melting point materi
- Acceptable deposition rates
- Autofrettage stresses protected
- No post-process surface finish req
- Accept dim. and densities over 50 cal
- Dry process
- Eliminate hazardous materials
- Eliminate air / water contamination
- Best suited for large caliber guns
  I.e. Larger target-to-tube distances

LARGE CALIBER EROSION MITIGATION TECHNOLOGY

Accomplishments and Plans

U.S. Army Benet Laboratories

ARDEC

Task	***Accomplishment***
Demonst[illegible] resistant behavior via *Electrodeposition by Fused Salts*	[illegible]arrels (liners) • 110 rounds from 105mm M68 barrel (liners)
Demonstrated *Biased Triode Sputtering* Process Technology	• 1500 rounds at 150 rounds/min for 10 bursts from 20mm M61A1 barrels (liners)
Demonstrated *Cylindrical Magnetron Sputtering (CMS)* for hi L/D Barrels	• Coated full length “Abrams-Simulator” 45mm barrels Origin wear rate equivalency demonstrated
Demonstrated enhanced adhesion with *CMS Ion Bombardment Sputtering via Pulsed Technology*	• 120mm barrel sections. Results show decreased [illegible]ck density indicating increased barrel life
Building *Pre-Production Sputtering Platform* at Watervliet Arsenal	• Full-length CMS platform currently under construction at Watervliet Arsenal. Initial Operational Capability by June 04.
Coat inserts & full length smoothbore, Large Caliber Barrels - *Abrams, FCS-LOS*	
Fire coated full length smoothbore, Large Caliber Barrels - *Abrams, FCS-LOS*	FY ’04 – ‘05

Summary of

TECHNICAL METRICS

Advanced Coatings for Large Caliber Guns

U.S. Army Benet Laboratories — ARDEC

CURRENT CHARACTERISTIC	Current state of HC CHROME PLATING	Desired end state for SPUTTERING	VERIFICATION TECHNIQUE	STATUS
Coating Morphology	Zone 2	Zone 2	Microscopy	yes
Coating Phase	Single	100% Alpha (Ta)	Microscopy	yes
		bcc (Cr)	Microscopy	yes
Hardness	1100 Knoop	200 - 300 Knoop	Microhardness (Ta)	yes
			Microhardness (Cr)	yes
Thermal Shock Resistance	Poor	Excellent	Pulsed Laser	yes
			Vented Erosion Sim	yes
Adhesion / Cohesion	Excellent	Excellent	Groove Testing	yes
			VES (Ta)	yes
			VES (Cr)	yes
Distribution over Length	.002 - .006 in.	Less than .0005		
Microscopy	yes (80”)			
Distribution around ID	.002 - .006 in.	Less than .0005		
Microscopy	yes			
Deposition Rate	.001 inches/hr	.001 inches/hr	Microscopy	no (.00075)
Coating Thickness	.002 - .006 in.	.004 - .006 in.	Microscopy	yes

INTERIM VALIDATION

In-process Assessment Challenge

Large Caliber Testing 400 rounds x $3500 ea = $1.4M plus range/personnel costs

- Too costly as an in-process assessment tool
- Design of Experiments nightmare
- Best used as final assessment against program metrics

Sub-Scale Development & Testing

- Economical approach ***as long as deposition process is scaleable***
- PVD processes for ID surfaces have proven to be “size-sensitive”
- Target-to-substrate distance is critical for consistent plasma generation
  - *Coating deposition rate*
  - *Coating distribution over length and circumference*
  - *Coating morphology, phase and adhesion quality*
- 25mm / 45mm experiences did not matched large caliber process needs/achievements
- Achieved improved adhesion on 1st 120mm deposition

Best approach - **Full scale process development w/valid sub-scale test methodology**

- requires a test methodology that minimizes deviations from gun parameters
- no multiple process development cycles
- no scaling assumptions

INTERIM COATINGS VALIDATION

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Vented Erosion Simulator (VES) Testing

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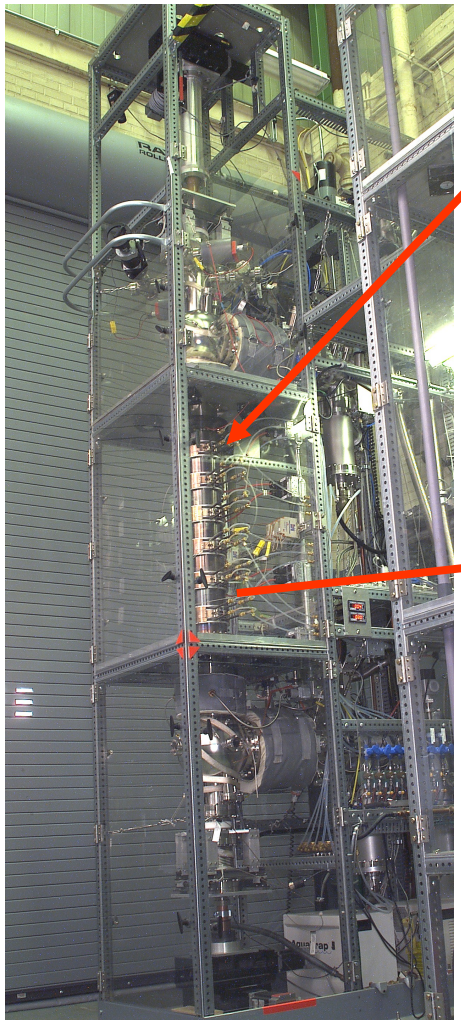
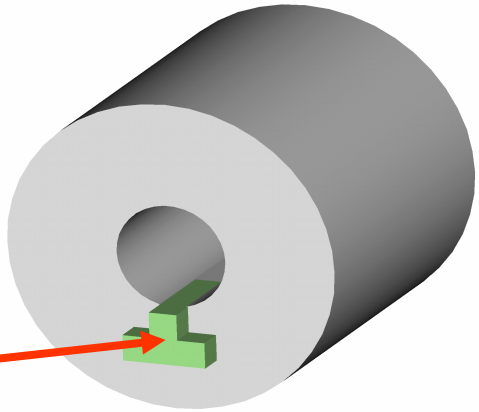
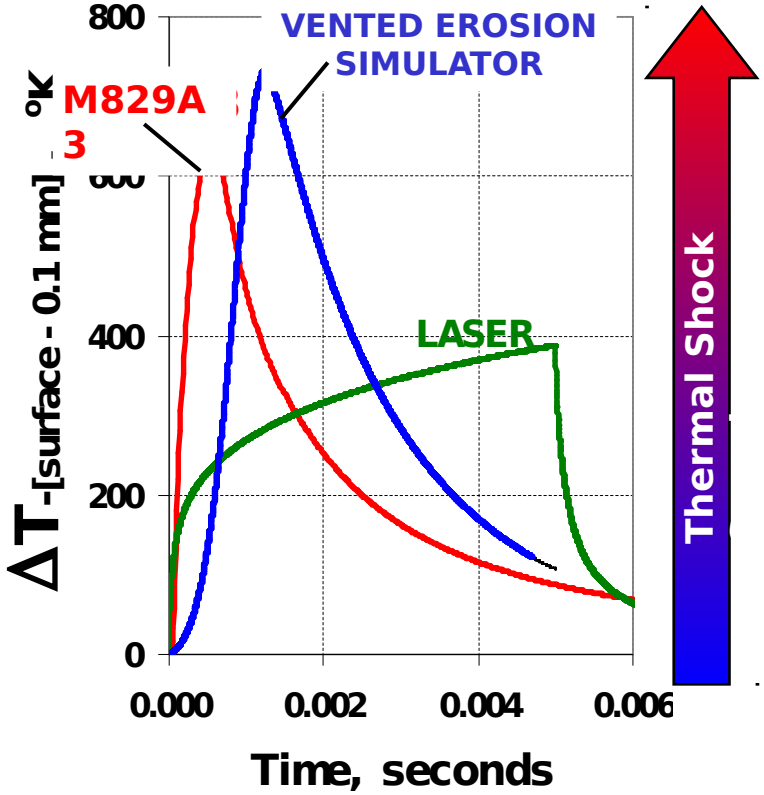






- Flame T & chemistry similar to M829A2/M829A3
- Accepts Large Caliber coated coupons *(eliminates process scaling)*
- Ballistically modeled & validated
- Substrate transformed to same depth as Lg Cal Gun
- Maintains critical T observed in current gun barrel

INTERIM COATINGS VALIDATION

U.S. Army Benet Laboratories

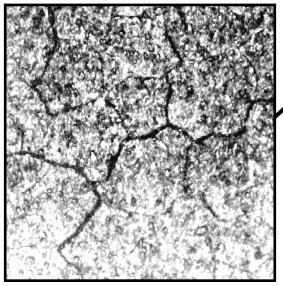
Vented Erosion Simulator (VES) Testing

ARDEC

SURFACE CRACK DENSITY

CROSS-SECTION

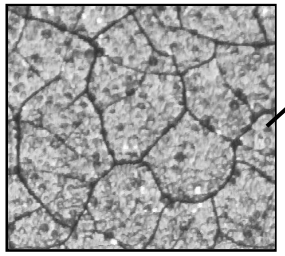
HC-Cr

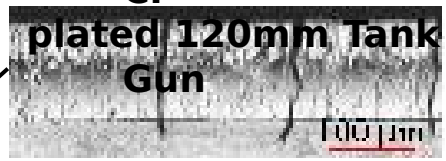


118 M829A3 Rounds fired from a production HC-Cr plated 120mm Tank Gun

Thermal-Chemical Erosion Equivalency of Vented Erosion Simulator

HC-Cr (VES)

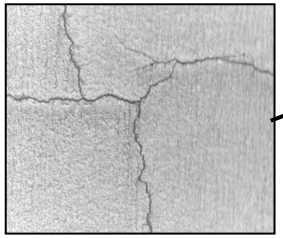




100 VES shots on a production HC-Cr plated 120mm Tank Gun Section

Erosion Reduction with CMS Tantalum as compared to Electrodeposited HC-Chromium

CMS-Cr (VES)



100 VES shots on a Sputtered Tantalum coated 120mm Tank Gun Section

LOWER CRACK DENSITY = BARREL LIFE

LO

LARGE CALIBER Pre-PRODUCTION Demonstration Platform

at Watervliet Arsenal – Initial Testing - June 04

U.S. Army Benet Laboratories

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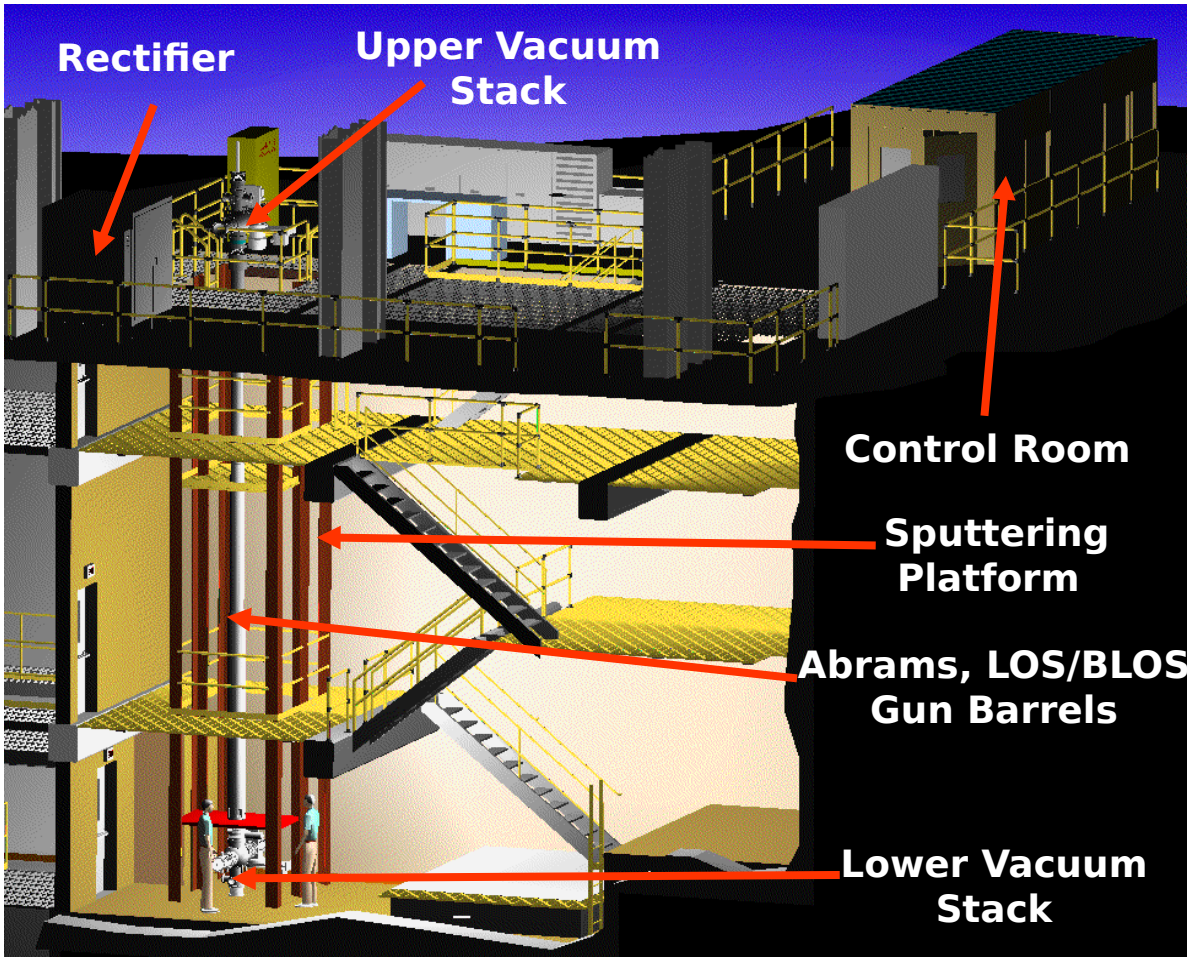

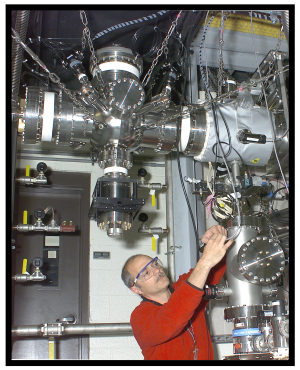

UPCOMING FIRING DEMONSTRATIONS

U.S. Army Benet Laboratories

Advanced Sputtered Coatings

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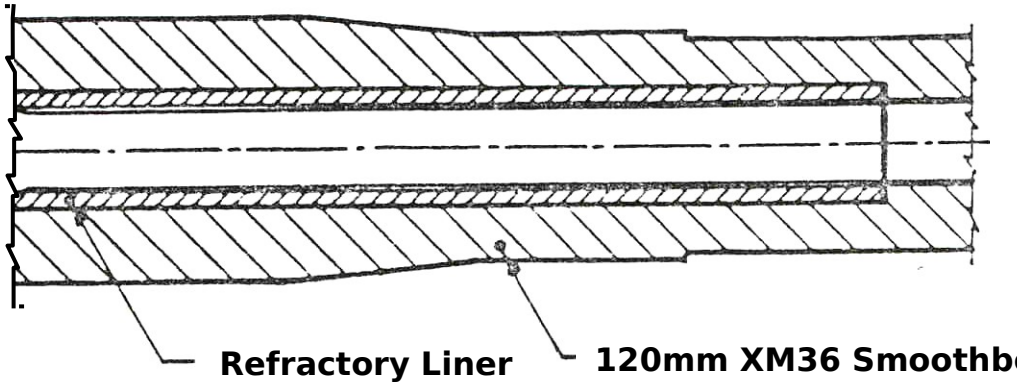

120mm XM36 Firing Test #1

- 120mm coated, shrink-fit liner
- May-June 04

FUTURE COMBAT SYSTEMS
FCS
One Team – The Army/DARPA/Industry

120mm XM36 Firing Test #2

- 120mm coated, shrink-fit liner
- Oct-Nov 04

120mm XM36 Sub-Scale Development & Testing

- Full-length monoblock coating test
- Mid FY05

BARREL COATING TECHNOLOGY

System Application Graphic

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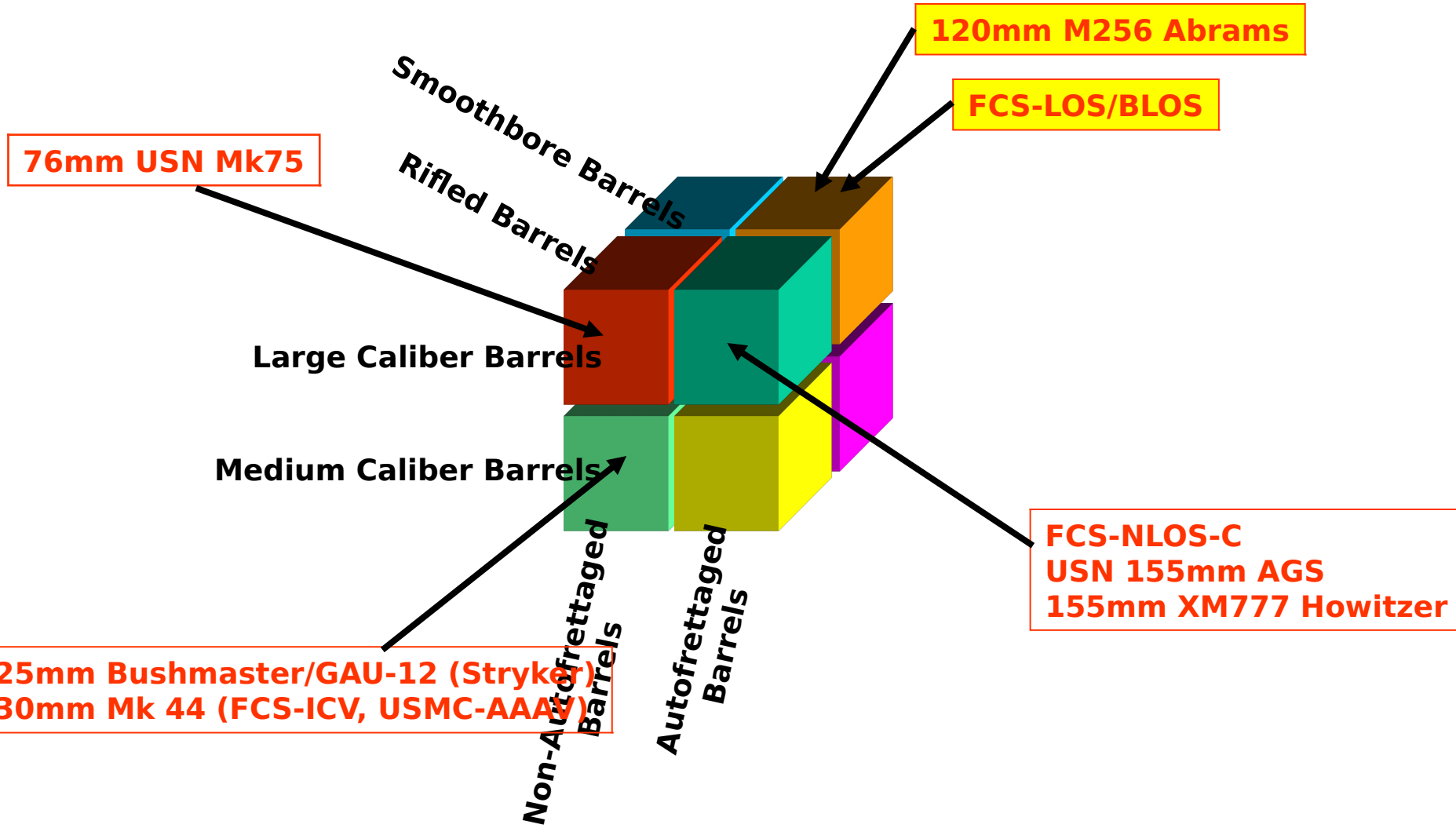

SUMMARY

- **Cylindrical Magnetron Sputtering results encouraging for large caliber systems**
  - Increased adhesion and bulk properties
  - All laboratory metrics achieved *(still improving deposition rate)*

- **Technology moving forward but slower than desired**
  - 30% loss in program funding – *War on Terror, FCS cuts, etc.*

- **Upcoming 120mm XM36 tests should be insightful**

- **Large Caliber Full-length Pre-Production Platform Initial Testing by June 2004**

- **Will one coating technology address all platforms ???**
  - Large Cal vs. Med Cal
  - Autofrettaged vs. Non-Autofrettaged
  - Smoothbore vs. Rifled bore